160Gbit/s, 1.6bit/s/Hz RZ-DQPSK Polarization-Multiplexed Transmission over 230km Fiber with TDC

Biljana Milivojevic (1), A. Fauzi Abas (1), A. Hidayat (1), Suhas Bhandare (1), David Sandel (1),
Reinhold Noé (1), Martin Guy (2), Martin Lapointe (2)
1: Univ. Paderborn, EIM-E, Warburger Str. 100, D-33098 Paderborn, Germany,
milivojevic/fauzi/hidayat/suhas/ sandel@ont.upb.de; noe@upb.de; 2: TeraXion, mguy/mlapointe@teraxion.com

Abstract *Residual chromatic dispersion is eliminated by a tunable CD compensator in one out of eight 4x40Gbit/s, 100GHz-spaced WDM channels. Polarizations, In-phase and quadrature channels are automatically demultiplexed using LiNbO$_3$ device and a 1-bit interferometer.*

Introduction

Polarization division multiplex [1-3] and DQPSK [2-7] transmission each can double fiber capacity by their increased spectral efficiency. Both techniques have been combined to transmit 4x10 Gbit/s per WDM channel [2, 3]. Here we report for the first time to our knowledge 4x40 Gbit/s per WDM channel transmission with automatic polarization control as well as a tunable chromatic dispersion compensation.

Transmission setup

Fig. 1 shows the RZ-DQPSK polarization division multiplex (PolDM) 4×40 Gbit/s per WDM channel transmission setup. Eight 100GHz-spaced WDM signals (192.3 ... 193.0 THz) are combined with equal polarizations and modulated together. The electrical part of the transmitter employs a 16:1 Infineon™ multiplexer which processes 16 2.5 Gbit/s 2^7-1 PRBS data streams, mutually delayed by multiples of 8 bits, and SHF modulator drivers for a Triquint dual drive DPSK modulator.

It is followed by an in-house developed all-fiber temperature-stabilized Mach-Zehnder interferometer with a differential delay of 3-symbol durations. The polarization dependent phase shift is < 500 MHz and the extinction ratio is ~24 dB. A piezo fiber stretcher is included in one of the arms for active phase control. At one interferometer output, a 192.5THz optical bandpass filter (BPF), a photoreceiver with a bandwidth of about 12GHz, and a subsequent RF diode detector are used to measure the RF power carried by the optical DQPSK signal. When the two optical signals are superimposed in quadrature, there is no interference and hence no RF power, except for the clock frequency that is outside the photoreceiver bandwidth. A quadrature control loop based on a 10 kHz lock-in detection scheme stabilizes the interferometer phase by minimizing the RF power . The 10 kHz phase modulation has a depth of ~0.01 rad (rms). The interferometer delay is a half-integer multiple of the inverse channel separation which means that in-phase and quadrature data streams are combined with alternating polarities from one WDM channel to the next. The channel spacing is fine-tuned so that each WDM channel contains a proper DQPSK signal. A Triquint dual drive modulator driven at half the clock rate carves 8-ps pulses and thereby generating the RZ-DQPSK signal for transmission.

Finally, the DQPSK signal is split and recombined with orthogonal polarizations with a differential delay of 2.8 ns. Since this polarization multiplexer was available, interleaving of orthogonally polarized pulses in the time domain was not tested. However, it is known that pulse interleaving increases the vulnerability against PMD distortions [8].

The optical signals are transmitted over 4 fiber spans with a total length of 230 km. These contain 170 km of SSMF and 60 km of NZDSF. DCF with a total dispersion of –2713 ps/nm is inserted between inline EDFAs. Fiber and DCF launch powers are –0.5 ... +4 dBm and –4.8 ... -3 dBm per WDM channel, respectively. EDFA input powers are –15 ... –10.5 dBm per WDM channel.

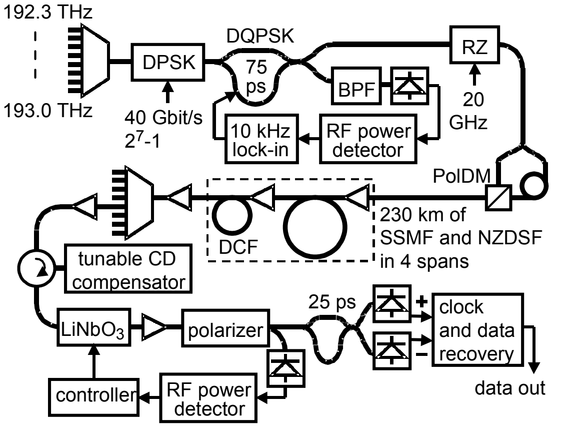

Fig. 1: 4x40Gbit/s per channel, RZ-DQPSK PolDM transmission

The receiver contains optical preamplifiers and a flat top C band DWDM DEMUX from Optun™. To receive the 192.5 THz (1557.366 nm) channel, a thermally tunable dispersion compensator (TDC) was used. It is based on a FBG and is coupled via circulator. It was set to -440 ps/nm, while the total tuning range was from -300 to -700 ps/nm. A LiNbO$_3$ polarization controller transforms the incoming signals so that the unwanted polarization is supressed in a fiber polarizer. Another 12GHz photoreceiver and a subsequent RF diode detector detects the broadband interference between both polarization channels. A controller minimizes this interference by properly setting the LiNbO$_3$ polarization controller.

Another Mach-Zehnder interferometer, with a delay of one symbol duration, demodulates the signal. For proper reception of in-phase and quadrature data channels, the phase difference of the delay demodulator is set either to 45° or 135°, using a piezo fiber stretcher. The demodulator outputs are connected to two high-speed photodetectors from u2t™, which in turn are connected to the differential inputs of a 1:16 Infineon™ demultiplexer with standard clock and data recovery. An advantage here is that an extra photodiode to recover the clock from the 40 GHz intensity modulation is not necessary. Note that the demodulated bit patterns in in-phase and quadrature data channels differ from the transmitted ones. The half rate clock signals in transmitter and receiver are generated by VCOs from WORK Microwave GmbH™.

Results

Fig. 2 shows measured Q factors for I and Q data channels back-to-back for all 8 WDM channels and for the dispersion-compensated 192.5 THz channel after over 230 km fiber. Error free transmission was possible for this channel with Q≥16.5 dB.

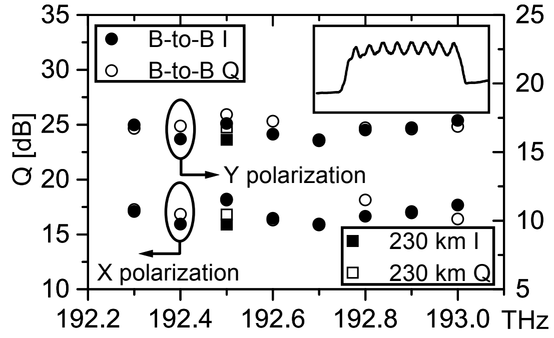

Fig. 2: Measured Q factors for I & Q data channels back-to-back and after transmission over 230 km fiber in 2 polarizations for 8 WDM channels (in inset).

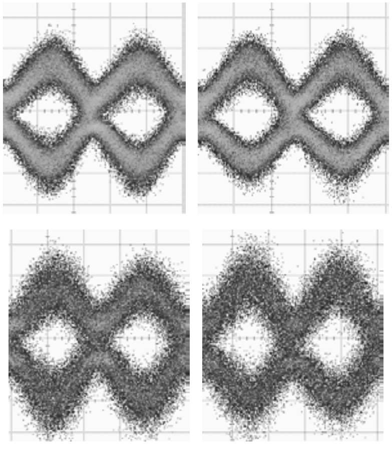

Fig. 3: Eye diagrams for I (left) & Q (right) data channel in one polarization; back-to-back (top) and after transmission over 230 km (bottom)

Fig. 3 shows the corresponding eye diagrams for 192.5THz channel in one polarization. The other polarization is very similar. Measured electrical interference spectra in the 12GHz photoreceiver after the polarizer for the best case (where the interference should disappear because polarizations are well aligned) and the worst case (when both polarizations are totally mixed) are displayed (at top and bottom) in Fig 4. The corresponding total RF powers are –22 and –8.5 dBm, respectively.

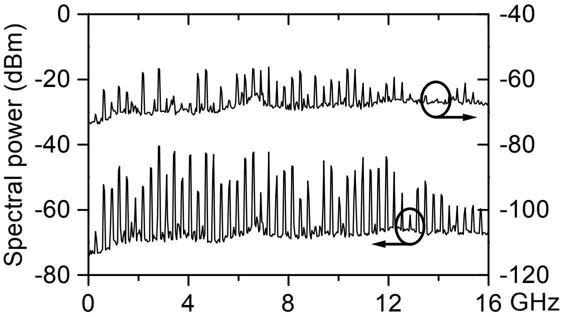

Fig. 4: Electrical interference spectra measured in the 12GHz photoreceiver after the polarizer (see text).

The eye diagrams before and after transmission had identical shapes, which suggests that the CD compensator itself did not introduce any significant penalty in the system, even though DQPSK is more sensitive to chromatic dispersion than DPSK or ASK. As the signal is transmitted, the in-phase part of optical amplifier noise modulates the pulse amplitudes. Self phase modulation converts this into a random phase modulation which limits permissible link lengths. This nonlinear phase noise is described in [9]. It scales with the square of the length and linearly with the symbol rate (taking into account that the linewidth tolerance scales also linearly with the symbol rate). Definitely, the use of FEC will relax the problem in practice.

Conclusions

We have transmitted 160 Gbit/s (4×40 Gbit/s RZ) on each of the 8 100GHz-spaced WDM channels in two polarizations and differentially encoded in two quadratures per channel. Fiber capacity is thereby quadrupled. The error free transmission over 230 km of fiber was achieved with Q>16.5 dB for one of the WDM channel for which the tunable dispersion compensator was available.

References

1 D. Sandel et al *ECOC 2001*, PD.B.1.4.
2 C. Wree et al *IEEE PTL* 15 (2003), 1303
3 Y. Zhu et al *OFC 2004*, TuF1
4 R. A. Griffin et al *OFC2002*, WX6C
5 P. S. Chao et al *IEEE PTL* 15 (2003), 473
6 H. Kim et al *IEEE PTL* 15 (2003), 769
7 N. Yoshikane et al *OFC2004*, PDP38
8 S. Hinz et al. Optics Express (2001), 136
9 J.P. Gordon et al *Optics Letters* 15, (1990), 1351